

M.TECH PROJECT REPORT

RSSI Based Indoor Passive Localization For Intrusion Detection And Tracking

By
RAM PRAVESH KUMAR
(EE10M14)

Adviser:
Dr. P.RAJALAKSHMI
DEPARTMENT OF ELECTRICAL ENGINEERING



INDIAN INSTITUTE OF TECHNOLOGY HYDERABAD

Ordinance Factory Estate , Yeddumailaram, Medak-502205.

Declaration

I declare that this written submission represents my ideas in my own words, and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

Ram Pravesh Kumar

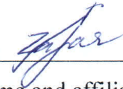
(Signature)

(RAM PRAVESH KUMAR)

(Roll No-EE10M14)

Approval Sheet

This thesis entitled RSSI Based Indoor Passive Localization For Intrusion Detection and Tracking Using Pervasive indoor Wireless Sensor Network by Ram Pravesh Kumar is approved for the degree of Master of Technology from IIT Hyderabad.

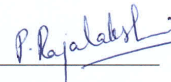


-Name and affiliation-

Examiner

-Name and affiliation-

Examiner



-Name and affiliation-

Adviser

-Name and affiliation-

Co-Adviser



-Name and affiliation-

Chairman

ACKNOWLEDGEMENTS

My deepest gratitude is to my advisor, Dr.P .Rajalakshami.I have been amazingly fortunate to have an advisor who gave me the freedom to explore on my own, and at the same time the guidance to recover when my steps faltered.Her patience and support helped me to finish this dissertation.

I would like to thank my family and friends and the one above all of us, the omnipresent God for the support they provided

A very special thanks to R.D.Praveen Kumar and V.Santhanakumar for their discussions throughout the project.

Finally I would like to thank family of IITH

DEDICATION

To the four pillars of my life: God, my family, my friends and my teachers.

Abstract

A real time system for intrusion detection and tracking based on wireless sensor network technology is designed by using the IITH mote which is developed and designed in IIT Hyderabad as the communication module in the network. This paper describes the Device-Free Passive Localization system based on RSSI. The main objective of this paper is to design a DFP Localization system that is easily redeployable, reconfigurable, easy to use, and operates in real time.

In addition the detection of humans is to be done. The embedded intrusion detection algorithm is designed so that it is able to cope with the limited resources, in terms of computational power and available memory space, of the microcontroller unit (MCU) found in the nodes. and various challenges and problem faced during the real test bed deployment and also proposed solutions to overcome them. We presented an alternative algorithm based on the minimum Euclidean distance classifier. Our result shows that the localization accuracy of this system is increased when using the proposed algorithm .

Contents

1	Introduction	8
1.1	localization	8
1.2	Wireless Sensor Network	8
1.3	Background and motivation	8
1.4	Scope and objectives	9
1.4.1	System requirements	10
1.5	Contributions	10
1.6	Structure	11
2	Wireless sensor networks	12
2.1	Short range wireless communication standards	12
2.1.1	Bluetooth	13
2.1.2	Wireless local area network (WLAN)	13
2.1.3	Ultra-wideband (UWB)	14
2.2	IEEE 802.15.4 protocols	14
2.2.1	WirelessHART	14
2.2.2	ZigBee	15
2.2.3	6LoWPAN	15
2.3	Multiple access methods	15
2.3.1	Time division multiple access	16
2.3.2	Frequency division multiple access	17
2.3.3	Carrier sense multiple access/collision avoidance	17
2.4	Network topology	18
2.5	The wireless medium	19
2.5.1	Phenomena effecting the wireless communication channel	19
2.5.2	Received signal strength indicator (RSSI)	21
3	The feasibility of localization based on RSSI	22
3.1	RSSI is a low cost approach for distance measurement in WSN	22
3.2	How to retrieve RSSI reading ?	22

3.3	How is the transmit power related to the signal strength in IITH Mote?	23
3.4	How is the RSSI value related with signal strength in IITH Mote?	23
3.5	The implementation details: the programs in motes, Base station, and Computer	24
3.6	How to save the RSSI readings to data file?	25
3.7	Why RSSI readings from different motes or different directions so diversified?	26
4	RSSI based intrusion detection	27
4.1	experimental testbed	28
4.2	Hardware description	29
4.3	Related Work	30
5	performance evaluation	36
6	Conclusion and future work	38

Chapter 1

Introduction

1.1 localization

Localization means to determine location of nodes in a network. With the support of some infrastructure, a node can determine its location in the network by extracting information received from the infrastructure; also by making a node to send signals periodically, the infrastructure can calculate the location of the node.

1.2 Wireless Sensor Network

Wireless Sensor Network (WSN) is a kind of Ad-hoc network, and is often infrastructure independent. Large amount of cheap motes construct the network by collaborating with each other, and the data sensed by each mote congregate to the base station. The transmission power for each mote is often low to avoid interfacing with each other. Thus the range of communication or range of connectivity is limited to some extent. In a quite large WSN, the readings from each mote may have to arrive at the base station via several steps. In sensor network, finding and maintaining a high efficient multi-hop routing algorithm is very important to guarantee the high reliability and low energy consuming. WSN is a kind of data centric network.

1.3 Background and motivation

Many location determination technologies have been proposed over the years, including: the GPS [1], infrared [2], ultrasonic [3], and radio frequency (RF) [4]. All these technologies share the requirement for a tracked object to carry

a device to be tracked. In addition many of these technologies require the device being tracked to actively participate in the localization process by running part of the localization algorithm. This allows the system to provide the user with its location and other services related to the estimated location [5], [6]. Despite becoming the enduring technology for navigation and tracking purposes, the global positioning system (GPS) presents also some limitations. i.e. a null or very limited functionality in indoor environments, and the need of having the users to carry an end device at all times.

Now a days, device-free localization (DFL) and tracking of people in indoor environments could potentially be exploited in a variety of applications, such as tracking of customers in shopping malls with the aim to analyze their reaction to products and advertisements placement, detection of intruders in critical buildings or infrastructures, localization. Wireless sensor networks (WSNs) represent a suitable technology to perform these tasks. A feasible solution is to extract useful information from the variations of the received signal strength indicator (RSSI) caused by the presence and movements of individuals inside the monitored area. Since in this case additional sensors such as cameras or infrareds are not used, the nodes forming the wireless network can be considered as radio frequency (RF) sensor

The received signal strength indicator (RSSI) has been traditionally exploited for nodes localization, distance estimation, and link quality assessment. Recent research has shown that variations of the RSSI in indoor environments where nodes have been deployed can be exploited to detect movements of people. Moreover, the time histories of the RSSI of multiple links allow reconstructing the path followed by the person inside the monitored area. This approach, though effective, requires the transmission of multiple raw RSSI time histories to a central sink node for offline analysis. This paper aims at applying distributed processing of the RSSI measurements for indoor surveillance purposes.

1.4 Scope and objectives

The scope of this thesis is to design and develop a realtime device-free localization (DFL) system that exploits radio signals to detect the presence of individuals. The system is used for positioning individuals and to track their movements in indoor environments. In addition, the aim is to investigate the characteristics of radio signal propagation in indoor environments and to study how the presence of people influences radio signal propagation.

The main objective of this thesis is to design a DFL system that is easily redeployable, remotely recon-

figurable, easy to use, and operates in real time.

1.4.1 System requirements

In this thesis, an embedded algorithm that processes the RSSI measurements and detects the intruder obstructing the line of sight (LoS) between communicating nodes is developed and implemented. The algorithm is designed so that it does not depend on the characteristic of the surrounding indoor environment and so that it does not include hard coded thresholds. In addition, the algorithm is designed so that it does not require training of the network in static conditions (i.e. when movement is not present inside the monitored area). The link obstructions caused by the intruder are notified to a central base station and then exploited to estimate the intruders position. The path of the intruder is tracked from the consecutive position estimates and the tracking application provides a reliable estimate of the intruders position and trajectory in realtime with minimal latency.

1.5 Contributions

Contributions of the author in the thesis are listed as follows:

- A device-free, wireless, real time, intrusions detection and tracking application for indoor environments is developed and tested. The proposed system is based on monitoring the changes in the RSSI caused by a person moving among or in the close proximity of communicating low power sensor nodes, operating in the 2.4 GHz industrial, scientific and medical (ISM) band.
- A comprehensive study of the radio channel and signal strength characteristics in indoor environments is performed to gain insight of the wireless medium. The results introduce design aspects for a RF based DFL system.
- The embedded RSSI intrusion detection algorithm and the real time tracking application were tested in the lab room of a university building, with a WSN consisting of 4 nodes and the two sink node. The test were conducted using two different network layouts and two different node intervals

1.6 Structure

The thesis is structured as follows. Chapter 2 provides an overview of wireless sensor networks, introduces the communication stack of the sensor nodes and the main phenomena affecting the wireless medium, and lists the related work. After describing the sensor networking platform used in the experiments, at the end of the chapter the radio channel characteristics and causes for RSSI variabilities are introduced. In Chapter 3 The feasibility of localization based on RSSI and How to retrieve RSSI reading ? Chapter 4 presents the developed intrusion detection and tracking application, i.e. the embedded algorithm executed to detect intrusions, four different methods to detect and estimate the position of the intruder, and the real time tracking application. The system is experimentally evaluated at the end in chapter 5. In the final chapter 6 conclusions and key observations of the thesis are summarized.

Chapter 2

Wireless sensor networks

A WSN consists of spatially distributed autonomous devices which communicate with one another exploiting a wireless medium. Each node typically consists of a RF transceiver, a MCU, an external power supply, and various types of sensors used to measure the surrounding environment. Initial research in the area of WSNs was mainly driven by military applications (e.g. Smart Dust (Kahn et al., 2000)) (Rmer and Mattern, 2004). Nowadays, WSNs are utilized for various purposes such as environmental monitoring (Hasler et al., 2009), structural health monitoring (Ceriotti et al., 2009 and Bocca et al., 2009), precision agriculture (Dong et al., 2010), etc.

The following sections cover fundamental issues related to WSNs. The chapter starts by introducing three different short range wireless communication standards and since the sensor networking platforms used in this thesis are based on the IEEE 802.15.4 standard, protocols of the standard are examined in more detail. In section 2.3 basic multiple access methods are introduced, and in the following section different network topologies are presented. The communication stack, which defines the interconnections of the wireless devices of IPv6 based low power wireless area network (6LoWPAN) is examined and section 2.5 covers the characteristics of the wireless medium and phenomena affecting radio signals. Work related to detecting and tracking movement of individuals with RF networks is discussed at the end of the chapter.

2.1 Short range wireless communication standards

There is a range of technologies enabling wireless connectivity, each designed for distinct purposes. Some technologies emphasize bandwidth, whereas oth-

ers call for low power consumption or inexpensive devices. Each standard is designed for some specific purpose in mind and rather than being competing technologies, they are complementary for one another, each best suitable for a specific application. In the following sections three different short range wireless communication standards are introduced.

2.1.1 Bluetooth

Bluetooth is a lowpower radio technology designed for short range and inexpensive devices. The technology was developed by Ericsson in 1994 and it has become the standard wireless solution for cordless computer accessories and mobile phone peripherals (Bluetooth, 2010). Its physical (PHY) layer and MAC layer are defined within the IEEE 802.15.1 protocol (IEEE 802.15.1, 2010). Bluetooth defines two different connectivity topologies: piconet and scatternet. A piconet is a wireless personal area network (WPAN) consisting of one master device and up to 7 active slave devices. The master node is used to synchronize the global clock of the network which is then used for frequency hopping. Communication is performed under the control of the master node. The slave nodes are able to communicate only to the master node in a point-to-point fashion, while the master node can transmit using point-to-multipoint broadcasts. Multiple piconets form a scatternet where the adjacent piconets are connected via a slave node. A slave node can be a part of multiple piconets, while a master node can be a slave at another piconet. However a node cannot be a master in multiple piconets. Suitability of Bluetooth in wireless sensor networks is studied

2.1.2 Wireless local area network (WLAN)

WLAN has been developed to replace the cables typical of local area networks (LANs). WLAN networks exploit radio technologies defined in the IEEE 802.11 standard providing secure, reliable and fast wireless communication at the expense of being complex and power hungry (IEEE 802.11, 2010). WLAN networks operate in the 2.4 GHz and 5 GHz frequency bands providing a bandwidth of 2-540 Mb/s (Wi-Fi Alliance, 2010). IEEE 802.11 offers two different network configurations: independent basic service set (IBSS) and extended service set (ESS). The IBSS is a group of working stations communicating directly to one another without the existence of an access point (AC). A set of working stations form a basic service set (BSS) which can access the distribution system (DS) via the ACs. The DS forms the backbone of the network and it is usually an Ethernet. Multiple BSSs connected together through the DS form the ESS network configuration.

2.1.3 Ultra-wideband (UWB)

UWB differs greatly from the other two radio technologies introduced above, being an impulse based radio solution. UWB utilizes a very broad portion of the radio spectrum, overlapping other radio technologies. The transmissions however use a very low signal energy level (-41.3 dBm/MHz) that does not interfere with coexisting narrowband radios, e.g. ZigBee and Bluetooth (WiMedia Alliance, 2010). UWB offers a short range high speed wireless communication reaching a bandwidth of over 110 Mb/s (up to 480 Mb/s), which can fulfill the rapid transfer requirements of bandwidth intensive files such as audio and video. Also there has been discussion on UWB possibly replacing high speed serial buses such as universal serial bus (USB) 2.0 and FireWire

2.2 IEEE 802.15.4 protocols

IEEE 802.15.4 is a standard for low rate wireless personal area networks (LR-WPANs), which specifies the PHY and MAC layers of the communication stack. The protocol is a basis for such wireless communication standards as WirelessHART, ZigBee, and 6LoWPAN, which all offer the upper layers of the communication stack. The standards intention is to offer devices with low cost, low power consumption, and low complexity.

2.2.1 WirelessHART

WirelessHART is a wireless communication standard designed for measurement and control applications in process plants. A WirelessHART network consists of three basic elements: wireless field device, gateway, and network manager. Field devices are used for process monitoring and control, whereas a gateway enables the communication between the field devices and a host application that is connected to an automation system bus. A network manager is responsible for network configuration, scheduling, route management, and network health monitoring. All devices in the network can act as routers in the wireless network and the network manager is in most cases integrated to the network gateway. The network uses IEEE 802.15.4 compatible radios for communication, and it enables a mesh network design for robust and redundant communication.

2.2.2 ZigBee

ZigBee is a higher layer communication protocol built on top of the IEEE 802.15.4 standard for LR-WPANs. ZigBee Alliance developed the ZigBee protocol to add the network, security and application software to the existing IEEE 802.15.4 standard (ZigBee Alliance, 2010). ZigBee is optimized for automation sensor networks, where there is no need for high bandwidth, but low power consumption, low latency and high quality of service (QoS) are required (Eriksson et al., 2008). The technology supports mesh networks consisting of at most $2^{16} = 65536$ devices co-operating with one another. There are three different types of ZigBee devices: coordinators, routers and end devices. A ZigBee coordinator is responsible for network formation, data storage, and linking networks together. The router enables multi-hop communication across devices and also links device groups together. A ZigBee end device consists of possible sensors and actuators that interact with the surroundings; the end device communicates only with router or coordinator devices

2.2.3 6LoWPAN

6LoWPAN is a low power wireless personal area network protocol that is based on the internet protocol version 6 (IPv6). The aim of the protocol is to provide lowpower radio communication that exploits the internet protocol (IP) addresses to enable internet connectivity. For the 6LoWPAN communication stack, an adaptation layer is defined to compress, fragment, and reassemble IPv6 headers and to enable mesh route forwarding. The adaptation layer is a standard proposed by the internet engineering task force (IETF). Because of the IP based communication, 6LoWPANs can be connected to other networks (e.g. WLAN, Ethernet, etc.) based on IP addresses via border routers that forward IP based packets between the different media

2.3 Multiple access methods

The nodes of a WSN share a common medium for communication, and without proper management of the medium, communication would be inefficient. Packet collisions would occur and packet delivery could not be assured within a certain time interval. Also the channel would be occupied most of the time with unnecessary retransmissions, due to improper management in the first place. Another point of view is that the whole capacity of the medium is not needed by one communication pair in the network, and the shared medium could also be used by other nodes. The channel division for

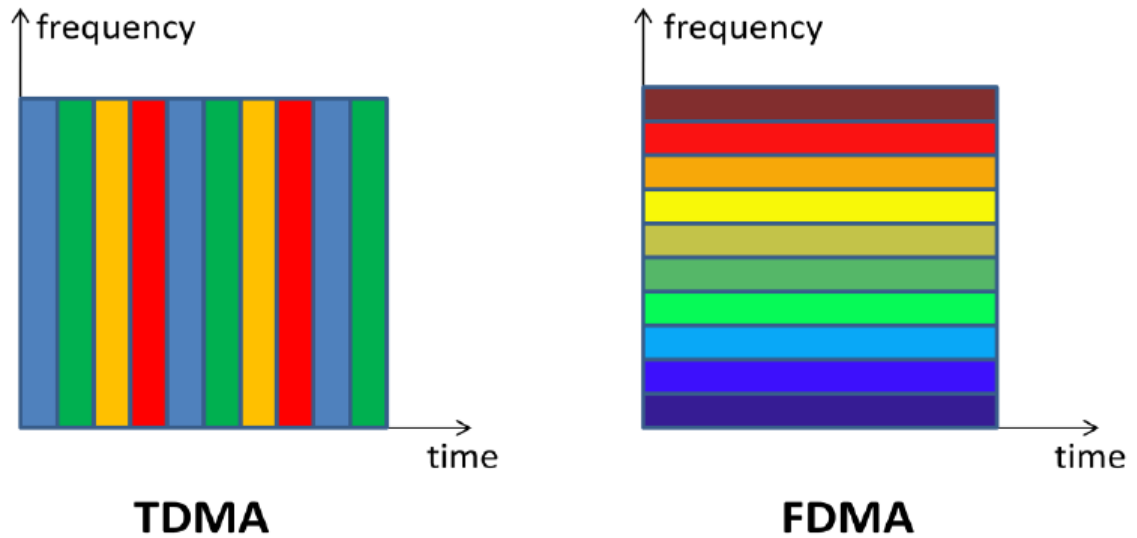


Figure 2.1: Channel allocation in respect to time and frequency by TDMA and FDMA techniques.

multiple users is called multiple access and it provides the methods to manage the limited resources of the radio channel efficiently

The multiple access methods can be classified into two distinct categories: conflict-free and contention protocols. Conflict-free protocols are not interfered by other transmission, and when a transmission is made it is ensured that it is successful. A conflict-free transmission can be assured by allocating the channel for the users either timely wise, frequency wise, or by a combination of the two. In TDMA, a single user is given the whole bandwidth for a fraction of time, whereas a single user is given a fraction of the bandwidth for the entire time in frequency division multiple access (FDMA) as shown in Figure. In contention protocols a transmission is not guaranteed to be successful, and the protocols must determine a routine to solve conflicts so that in the end the transmission can be assured. The benefit of contention based protocols is that idle users do not consume the scarce resources of the radio channel. An example of a contention protocol is carrier sense multiple access (CSMA).

2.3.1 Time division multiple access

In the TDMA protocol the time axis is divided into super frames, also denoted as cycles or frames. Each super frame is divided into smaller time slots, and each node in the network is assigned a time slot that they can use. During

the time slot the whole bandwidth is devoted to that one node. The cycles are periodic and each node has the same time slot in each frame. In order to exploit TDMA, the network has to be synchronized, so that each node in the network knows when they are allowed to transmit and when they should expect packets from other nodes. Since the time instances for communication are known, the nodes are able to turn off their radio to conserve power when scheduled communications are not expected. Downsides of TDMA are that it introduces communication delay and it is also inefficient since it allocates the whole bandwidth for the assigned slot of time

2.3.2 Frequency division multiple access

The FDMA protocol resembles TDMA, but instead of dividing the time space, it separates the frequency band to smaller portions called sub bands or channels. Each node in the network is assigned a distinct channel to operate on, and in this way every user is guaranteed a constant bandwidth at all times. This aspect is advantageous in applications where minor communication delays are permitted, and the throughput has to be guaranteed. The disadvantage of FDMA is that the channel is occupied at all times by the user even though no transmissions are made, decreasing the efficiency of the channel. Another downside of the technique is caused by the limited number of channels available which decreases the scalability of the network (Eriksson et al., 2008). Figure:2.1 presents the division of time and frequency space corresponding to TDMA and FDMA protocol.

2.3.3 Carrier sense multiple access/collision avoidance

Carrier sense multiple access with collision avoidance (CSMA/CA) is a contention based multiple access method which does not depend on a coordinator device to manage the channel. The underlying concept is that the transmitting nodes listen to the channel before communication and if the channel is sensed to be idle a transmission can be successfully made. If the medium is sensed to be busy, the transmission is delayed to a later time instance. The CSMA/CA protocol is a widely adopted technique in wireless networks. The collision avoidance in the CSMA/CA is maintained with a handshake routine between the communicating nodes. Before transmission of a data packet, a source node asks permission for transmission from the receiver by sending a short request to send (RTS) packet. If the destination receives the RTS packet correctly, it corresponds to a situation where it is not receiving packets from other nodes at the time. The receiver acknowledges the RTS with a clear to send (CTS) packet, and if received correctly at the source node the

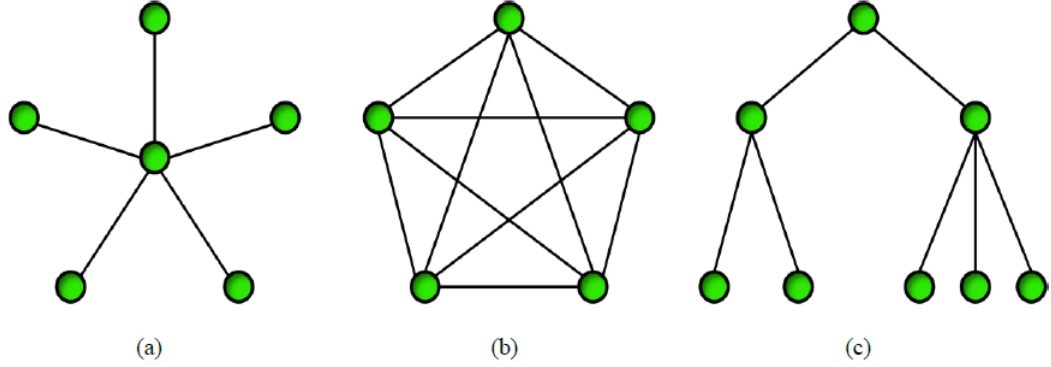


Figure 2.2: Three distinct network topologies: star (a), mesh (b), and tree (c) topology.

actual data packet is sent. After transmitting the data packet the source node waits for an acknowledgement (ACK) message from the receiver. If CTS is not received upon a certain time period, the source assumes that the packet has collided and a retransmission is attempted after a random backoff period. A backoff period is also launched in situations where the source senses that the channel is busy.

2.4 Network topology

Network topology is defined as the conjunction of various nodes in the wireless network and it is one of the key design factors of WSNs (Eriksson et al., 2008). The network topology effects heavily on communication traffic, QoS, power consumption of the network, and complexity of the realization. Three basic network topologies are the star, mesh and tree topology and they are described below in respective order. It is also possible to combine various topologies in different parts of the network to utilize the desirable features of each topology.

In wireless networks with a star topology, each node of the network communicates solely to a central node in a point-to-point fashion. The central node may act as a repeater or as an access point to the network. Advantage of the star network is its simplicity, but its disadvantage is its intolerability to failures. If the central node dies the whole network collapses. A star topology is presented in Figure 2.2 (a). In a mesh topology, depicted in Figure 2.2(b), every node in the network can act as a router and packets can be delivered from the source to the destination via multiple routes. The mesh topology is said to be fully connected, meaning that each node is connected

to every other node in the network. Mesh topology provides robustness to the network, since broken links can be replaced by a compensatory path, supposing that there is more than one node within the communication range. A drawback of the mesh topology is the relatively heavy routing protocol.

A tree topology is a hierarchical structure consisting of a root node and lower level nodes (i.e. children). The root node forms the top level of the hierarchy and it can have one or multiple children. These children constitute the second level of the tree, and they act as the parents for the third level nodes. Each node in the tree has exactly one parent, excluding the root node, and possibly multiple children. A tree topology must have at least three levels of hierarchy, since otherwise it would form a star. The routing protocol of the topology can be made relatively light and the number of point-to-point connections is one less than the number of nodes (cf. $m(m-1)/2$ for a fully connected mesh topology, where m is the number of nodes). As in a star network, a tree topology is also vulnerable to broken links, where a link failure high in the hierarchy can cause whole portions of the network to collapse.

2.5 The wireless medium

Wireless sensor networks deploy radio waves as the physical means to transmit data. Radio signals are a type of electromagnetic radiation with a certain amplitude, frequency, and wave length. In ideal circumstances (e.g. free space, vacuum), the phenomena effecting radio signal propagation (e.g. distance attenuation) are well known. However, most of the wireless networks are deployed in real world environments, where the wireless communication channel is exposed to multiple phenomena that have a negative impact on it. Such phenomena, to name the most common, include: multipath, distortion, power loss, fading, shadowing, noise and interference. In the next section, a few of these phenomenas are explained.

2.5.1 Phenomena effecting the wireless communication channel

Power loss refers to the decaying energy of the carrier signal, which is caused by damping in the medium (Stallings, 2004). The energy of the carrier signal deviates to a sphere surface once the signal is broadcasted from the antenna. The surface of the sphere is proportional to the square of the distance from the antenna and this formulation sets a relation between the signal power and the distance from the transmitting antenna as follows:

$$p \propto d^{-2},$$

where P is the power of the carrier signal and d is the distance from the transmitter antenna.

Multipath is a phenomenon in which a transmitted signal travels via multiple routes from the transmitter to the receiver (Eriksson et al., 2008). The traveled distance is different for every signal and because of this, the signals are not received simultaneously and phase difference results into interference. Multipath can be caused by three different phenomenas: reflection, diffraction, and scattering. Reflections are caused by the carrier signal bouncing off obstructions. Diffraction can result when the radio signal encounters an obstacle, and it can be described as the bending of radio signals around small objects and the spreading of radio waves past small openings. Scattering is a physical phenomenon in which the carrier signal changes the direction of propagation due to the non-homogenous medium it travels through

Fading in a wireless communication channel is caused by the above mentioned multipath effect and it can be divided into two categories: the Doppler spread and the delay spread (Zhang et al., 2003). The Doppler spread is caused by the movement of the receiver or the transmitter, which causes a change in the absolute velocity of the signal. The delay spread is caused by the changes in the close proximity environment. For example, a person who walks in the close proximity of the transmitting node causes multipath to change dynamically causing variation in the received signal power, a phenomenon referred as multipath fading. Correspondingly a person who is in between a communicating node pair can cause strong attenuation in the signal and this is referred as shadowing (Patwari and Wilson, 2010).

Interference is generally referred to as the unwanted additive disturbance to the transmitted signal and it can be divided into two classes: adjacent channel interference and co-channel interference (Siva Ram Murthy and Manoj, 2004). In the adjacent channel interference, signals in nearby frequencies have components outside their allocated bandwidth, and these components can interfere with the communication on neighboring frequency bands. Cochannel interference is due to other systems using the same transmission frequency. Possible sources of co-channel interference are networks operating on the same channel (e.g. WLAN). Most wireless sensor nodes are highly sensitive to interference, because of the low-power radio and it can result to packet drops and data errors, which can in the worst case, weaken the performance of the network.

2.5.2 Received signal strength indicator (RSSI)

In wireless communications, RSSI is a measurement of the signal strength in the received radio signal. The RSSI measurement provided by the RF transceiver is unitless, where the maximum value depends on the supplier and the range of RSSI values provided by the vendor is relative to the actual power, which is expressed in mW or dBm. However, each supplier provides their own accuracy, scale, and offset level for the measurement.

The RSSI measurement is the relative power in decibels (dBm) to the measured power referenced to one milliwatt (mW). Zero dBm corresponds to one mW, and to double the power means an increase of roughly 3 dBm. Respectively, to decrease the power in half is analogous to lowering the power by -3 dBm. The power in dBm can be expressed as a function of the power in mW as follows:

$$P_{dBm} = 10 \log P_{mw}$$

where P_{dBm} is the power in dBm and P_{mW} is the power in mW.

In recent years, RSSI has attracted a lot of attention in the area of wireless communication and WSN research. The reason for this is that the measure is a standard feature in most radios, so additional sensors are not needed. In addition, it doesn't require additional power consumption. The use of RSSI is extensive as it has been utilized for radio link quality assessment (Srinivasan and Levis, 2006a), nodes localization (Zanca et al., 2008), surveillance applications (Hussain et al., 2008), packets reception rate modeling (Srinivasan et al., 2006b), and transmission power control (Lin et al., 2006).

Despite the vast usage of the RSSI, the dynamics of this measurement are still difficult, if not impossible, to predict or model. Many parameters can influence the measure: in addition to multipath, fading, and shadowing, the transmitter and receiver variability, as well as the antenna orientation, can impact the measured RSSI value (Lymberopoulos et al., 2006). Moreover, the nodes spatial displacement and the surrounding environment contribute to RSSI variation.

Chapter 3

The feasibility of localization based on RSSI

3.1 RSSI is a low cost approach for distance measurement in WSN

RSSI based ranging and localization can be a cheap alternative to the high costs and complexity involved with other localization techniques. The requirements for the localization accuracy are not very strict, and our clients are also concerned about the cost of the whole system. RSSI-based ranging and localization is the first option that comes to our mind.

3.2 How to retrieve RSSI reading ?

In the lab, the wireless sensor modules we are using are motes made by IIT Hyderabad named IITH Mote and the software foundation is Tiny-OS, which is an open source embedded operation system designed to support tens of wireless sensor modules from different manufacturers.

The RSSI means Received Signal Strength Indication. Once a mote receives a packet message, at the time we get the payload, we can also read the RSSI indication. Suppose in a wireless sensor network topology, we have four motes which broadcast packet messages periodically. At the base station, these packet messages, in which mote ID is included, can be retrieved and the corresponding RSSI indication can be sampled.

Because the base station is connected to the serial port, these RSSI readings can be forwarded to the computer side, where we can use a java application to display these data in real time. If the data is stable,

Register Bits	Values[3:0]	Output Power[dBm]
	0x0	+3.0
	0x1	+2.6
	0x2	+2.1
	0x3	+1.6
	0x4	+1.1
	0x5	+0.5
	0x6	-0.2
	0x7	-1.2
	0x8	-2.2
	0x9	-3.2
	0xA	-4.2
	0xB	-5.2
	0xC	-7.2
	0xD	-9.2
	0xE	-12.2
	0xF	-17.2

Table 3.1:

we can save the data to a file. After that, we can process the data to get the function relationship between RSSI reading and distance.

3.3 How is the transmit power related to the signal strength in IITH Mote?

AT86RF230 is the transceiver on the IITH mote. By setting the register bits TX_{PWR} , we can set up the transmission power. The actual power output corresponds to the register value as showed in the table.3.1:

3.4 How is the RSSI value related with signal strength in IITH Mote?

The RSSI is a 5-bit value indicating the receive power in the selected channel, in steps of 3dB. The register value is represented in the lowest five bits [4:0] and the range is 0–28. An RSSI value of 0 indicates an RF input power less than -91dBm. For an RSSI value in the range of 1 to 28, the RF input power can be calculated as follows:

$$PRF = RSSI_BASE_VAL + 3*(RSSI - 1)$$

Thus, the dynamic range of PRF is 81dBm. Because the typical value of *RSSI_BASE_VAL* is -91dBm, the value range of PRF is from -91dBm to -10dBm.

Please note that, in IITH mote, it is not recommended to read the RSSI value when using the Extended Operating Mode. The automatically generated ED value should be used alternatively.

ED means the receiver Energy Detection measurement, and its value is calculated by averaging RSSI values over eight symbols (128us). The *PHY_ED_LEVEL* is an 8 bit register. The ED value of IITH mote radio transceiver has a valid range from 0 to 81 with a resolution of 1dB. Value zero indicates that the measure energy is less than -91dBm. Due to environmental conditions (temperature, voltage, semiconductor parameters, etc.) the computed energy value has an accuracy of 5dBm.

So, we can see that the receive signal strength that we read out from IITH MOTE is actually ED (Energy Detection), not the RSSI (the value of the register). The range of ED is from 0 to 81, corresponding to signal strength power from -91dBm to -10dBm.

3.5 The implementation details: the programs in motes, Base station, and Computer

Please note that the RSSI readings are closely related to the message receiving. In a scenario with many motes as transmitters and one mote in the base station to do the measurement of RSSI, we have to ensure that the packages from different transmitter don't collision with each other. The best way is that these packages arrive in different time slot.

In my implementation, the software is divided into three parts: programme in transmitter, programme in base station, and program in a computer.

The base station is a bridge between the transmitter and computer. In down stream direction, the base station can forward the parameter settings from the computer to all the transmitters; in up stream direction, when the base station receives a message from the transmitter, it starts to read out the RSSI value provided by the radio signal demodulator on the board. After that, the RSSI value is put in the payload which is received from one transmitter, and the new formed message is forwarded to the computer

through the serial port.

All transmitters broadcast structured messages periodically. The period of the transmission for all transmitters is the same, and can be set up by the command from the computer. However, after each transmitter receives a command from the computer, it enables a timer to do the delay before the periodical transmit. The delay time for each mote is a random number between 0 and the transmission period.

In the computer side, the oscilloscope application is modified to retrieve data from the serial port and display the data using graphs in real time. In the GUI window of oscilloscope application, the number of nodes can be discerned out through the contents of the raw data. Each node is represented by a graph of specific color. The x-axis is the packet counter number and the y-axis is the sensor reading. The GUI can also allow us to adapt the visible portion of the y-axis to a plausible range. For RSSI readings from IRIS motes, 081 is appropriate.

3.6 How to save the RSSI readings to data file?

In my implementation, two extra classes are added to the oscilloscope application. One class is related to the file processing, including `openfile()`, `recordfile()`, and `closefile()` methods. Another class is about record processing.

Oscilloscope is a data driven software. Whenever a new packet data is received, the data retrieved from the packet is used to update the graph in the GUI. At the same time, the data can be formed as a new record and added to the opened file.

By modifying the function of Clear button, I add the interface of saving the record to the file by closing the file handle. Also added is another interface to prompt the user to enter the file name for the next file. From the fig.4.3, we can see clearly that the RSSI readings are generally stable. However, if there are scenario changes such as obstacle intrusion or moving, the readings will fluctuate.

How can we design a filter to filter out the unqualified data? In my implementation, I adopted a pattern-match approach.

As a transmitter, each mote changes their transmission power according to a pattern, such as changing from the highest to the lowest power periodically. At the computer side, as a receiver, the RSSI readings is expected to vary according to the pattern of the transmit power.

If the RSSI readings vary in the same pattern, we can say RSSI readings are stable; if there are fluctuations in the RSSI reading pattern, we can assume that the RSSI readings are deteriorated by the obstacle change in the scenario, and the data in this time window will be thrown away.

3.7 Why RSSI readings from different motes or different directions so diversified?

We can conclude that the diversification of RSSI readings from motes with same distance away is slightly related to motes because all motes as transmitters are calibrated. The diversification is mainly caused by the anisotropic properties of antenna and media through which the radio propagates. Just as seen from the graph below, the radio connectivity over space is not disc-like.

Chapter 4

RSSI based intrusion detection

In recent years, there has been an increasing interest in utilizing RSSI for surveillance and motion tracking purposes. This measure has been found to be useful for these intentions since RSSI measurements are nearly constant in a static environment, but show increasing variance when the conditions change, e.g. when a person walks through the area.

The related work introduced in section 3.3 confirms the validity of using the RSSI for detecting people inside the monitored area. In this thesis focuses on processing the RSSI measurements locally in the nodes in real-time while the application is running. RSSI measurements are analyzed externally and the nodes in the network are not aware of the intrusions. Also in some cases the measurements are post-processed after run time.

The aim of this thesis is to create a WSN capable of detecting the intrusion caused by a person, estimate the position from the aggregated data and to track the intruder in real-time inside the monitored area. The intrusion detection is performed in a distributed fashion, locally by each node, only by means of processing the RSSI measurements. The intrusions sensed by individual nodes are sent to the sink node. Situation awareness is obtained by aggregating the alerts of all nodes and tracking is performed in real-time on a computer connected to the sink node. In addition.

In this chapter an intrusion detection system is introduced and since the RSSI measurements vary unpredictably, no information can be retrieved from the magnitude of the RSSI. For example if a person would be located in the area where a new WSN is set up at the time of deployment, the RSSI would not indicate the presence of the person supposing that the person would stay still at all times.

4.1 experimental testbed

The entire experiment has been carried out in an indoor environment. The RSSI measurements are prone to noise and interference, which leads to error in localization. Hence to provide ideal environment we have taken the following precautions:

- All the deployed nodes are kept at same altitude from surface of floor.
- Each IITH mote is supplied with USB power supply, so as to ensure that the battery power is same at all the nodes.
- All the deployed nodes are in line of sight with the base node and no obstacle is present in between.
- Since the antenna of base node is not isotropic, we have deployed the sensor nodes only in the antenna direction of base node.
- To avoid interference, we have taken measures to see that no other device working in range of 2.4 GHz is present in the vicinity of experimental location.

We have carried out the experiment with six IITH mote .four of them is working as a transmitter and rest two mote is working as a receiver with in our lab environment. The nodes are deployed at fixed distances from base node and the Localization error is estimated by comparing the distances calculated by mean RSS values. In our experiments we will show that a subject can be successfully localized in a home environment using our PC DfP method. The deployment takes place in the class room cabin in the institute .The room is quite cluttered, and has rich multi-path sources including table, desk, chair. The room dimension is 9 X 9 square feet and 7 feet in height. The floor and the walls are wallboard on construct. Our experimental setup consists of host PC serving as the system manager, and transmitters and receivers. In our system, each transmitter broadcasts a 10-byte packet every 250 milliseconds. The receivers will receive the captured packets and forward them to the host PC for data collection and analysis.

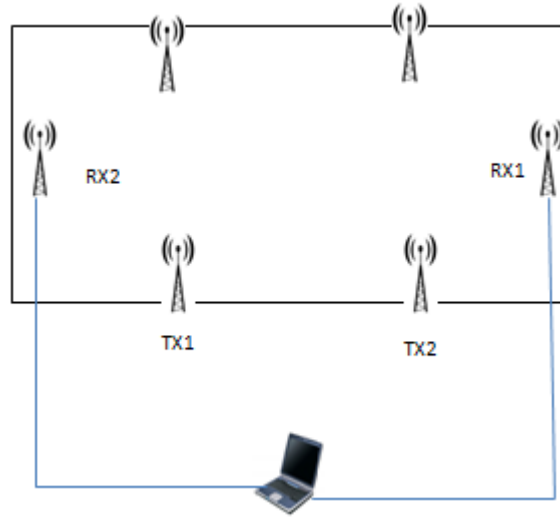


Figure 4.1: TX,RX-IITH mote will work as transciever .

4.2 Hardware description

IITH mote is an ultra-low power wireless module for use in wireless sensor networks, monitoring applications, and rapid application prototyping. IITH mote leverages industry standards like IEEE 802.15.4 to interoperate seamlessly with other devices. By using industry standards, integrating humidity, temperature, and light sensors, and providing flexible interconnection with peripherals, IITH mote enables a wide range of mesh network applications. With Tiny-OS support out-of-the-box, IITH mote leverages emerging wireless protocols and the open source software movement. IITH mote is part of a line of modules enabling the easy compatibility of interfacing any sensor board to it .

Key Features :

- 250 kbps, 2.4 GHz IEEE 802.15.4 Atmel Transceiver.
- Interoperability with other IEEE 802.15.4 devices.
- Atmel ATmega1281 with 8k RAM and 128k programming flash and 512k serial flash.

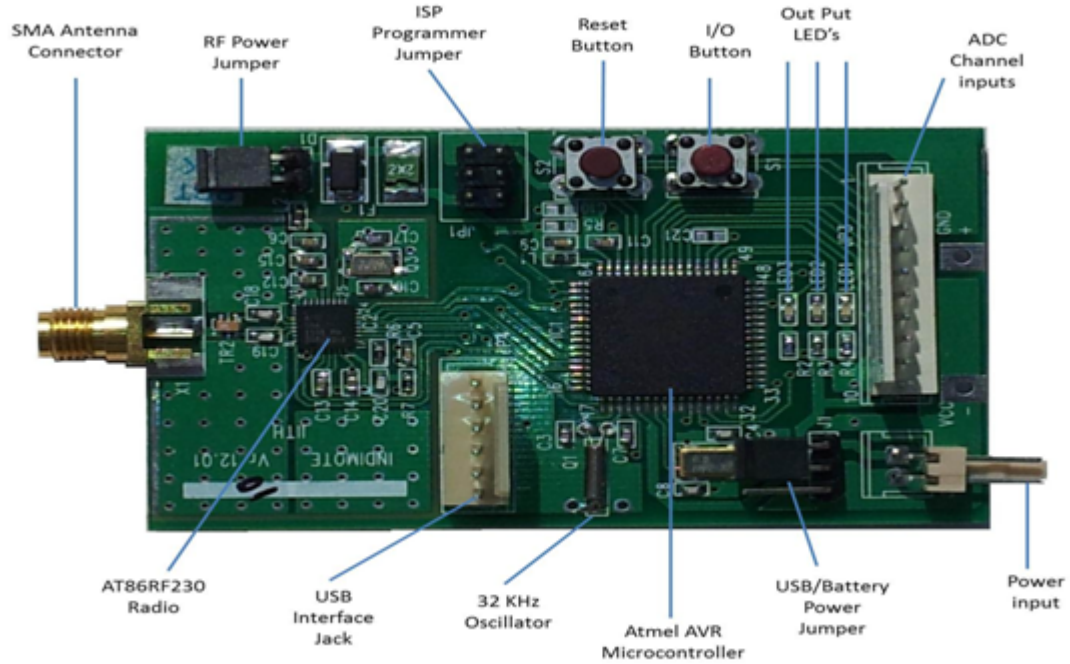


Figure 4.2: Photograph showing different parts of the IITH mote .

- Integrated ADC, Supply Voltage Supervisor.
- Integrated onboard antenna with 50m range indoors / 300m range outdoors.

4.3 Related Work

3.3.1.system architecture and organization :

The architecture of a DFP system is shown in fig 3.1 .it consist of four transmitter and two receiver along with DFP server.the DFP server is PC which performs the computations on RSSI streams and initiate action.

Organization of this device free passive localization is a.sending and receiving packets of RSSI. b. storing the received packets in the database, c. reading the values from the database and using algorithms on the values to locate the person.

a.Sending and Receiving packets: For sending and receiving packets, IITH motes are used as transmitters and receivers.in first step receiver will

record RSSI for all radio links when the deployed area is empty.in second step receiver will capture the RSSI changes for all the radio link with the user present and compare with the RSSI in step1.in step-3 summarize the relationship between RSSI change for all radio link and users position

b.Storing the values: For storing the values from the sensor motes, MYSQL database is used.

c.Algorithm:In monitoring mode algorithm will run in system server .For finding the cost matrix, Euclidean shortest path and to find the shortest path Dynamic Time Warping algorithm is used.

3.3.2.Detection of an Intruder

3.3.2.1.Moving Average Based Detection:

In moving Average detection technique detection determined by comparing two moving averages of received signal strength indicators with possibly different window sizes.if q_i be a series of measurements over time for a particular receiver to a transmitter the average $\alpha_{1,k}$ and $\alpha_{2,k}$ are define as follows for time index k.

$$\alpha_{1,k} = \frac{1}{w_l} \cdot \sum_{i=k}^{k+w_l-1} q_i \quad (4.1)$$

$$\alpha_{2,k} = \frac{1}{w_s} \cdot \sum_{i=k+w_l}^{k+w_l+w_s-1} q_i \quad (4.2)$$

w_l and w_s are the window lengths for the two averages $\alpha_{1,k}$ and $\alpha_{2,k}$ respectively.when the relative difference between the averages exceeds a parameter τ

$$\left| \frac{\alpha_{1,k} - \alpha_{2,k}}{\alpha_{1,k}} \right| > \tau \quad (4.3)$$

we declare an event detection for the time corresponding to $t = k + w_s$.the system server recomputes $\alpha_{1,k}$ and $\alpha_{2,k}$ periodically to check for event detection.

Here w_l window represents history of static situation,and the w_s window represents an estimate of the current state,and when current state differ from the history we suspect the intrusion .the system server computes $\alpha_{1,k}$ and $\alpha_{2,k}$ for each time index k in the time period of interest to check for detection.

3.3.2.2.Moving Variance Based Detection:

In moving Variance based detection technique is similar to the moving average except that it based on moving variance of the raw data and compares it to the variance during the silence period.w be the the window size .we compute the variance, v_t as:

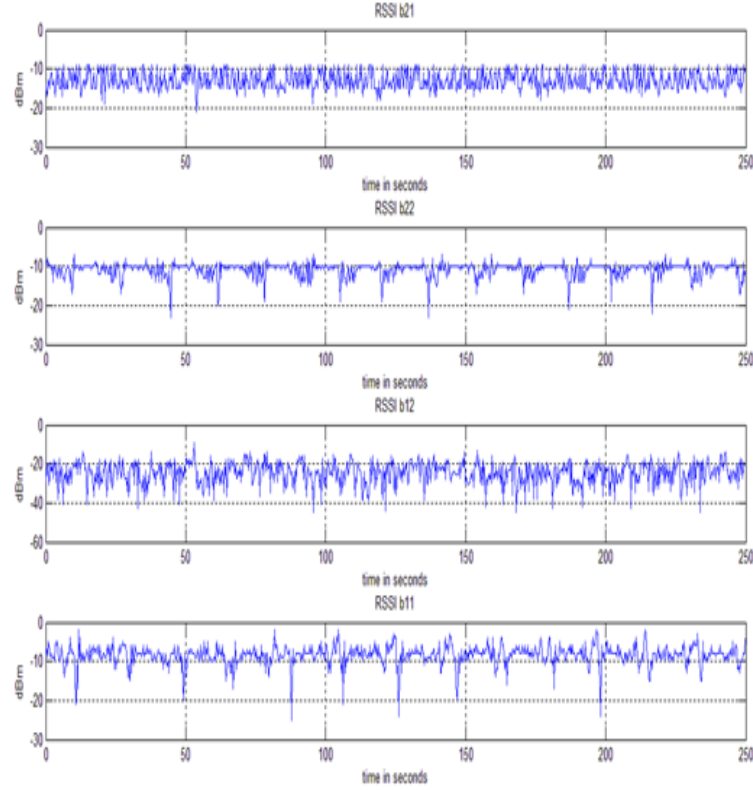


Figure 4.3: The RSSI values measured from the deployed sensor nodes are discrete in nature and are not constant. First we deployed IITH node at room and corresponding measured RSSI values are shown in fig3. Here RSSI received by receiver b2 are b21 and b22 which is transmitted by two transmitter t1 and t2 respectively and RSSI received by receiver b1 are b11 and b12 which is Transmitted by transmitter t1 and t2 respectively .

$$\bar{v}_t = \frac{1}{t_{end} - t_{start} + 1} \cdot \sum_{t=t_{start}}^{t_{end}} v_t \quad (4.4)$$

$$\sigma_v = \sqrt{\frac{1}{w} \cdot \sum_{t=t_{start}}^{t_{end}} (v_t - \bar{v}_t)^2} \quad (4.5)$$

3.3.2.3. Relative Variance Based Detection:

Relative variance technique is based on observation that, when a person is moving on the line of sight in a cabin then for a given stream the variance of the RSS stream Var_{on} is higher than the variance of RSS of a stream during absence Var_{off} by covering different areas of a cabin using different stream from transmitter to receiver we can detect whether an entity exists in any of the areas of a cabin based on relative variance $\frac{Var_{oni}}{Var_{offi}}$ when relative variance for a given stream $\frac{Var_{oni}}{Var_{offi}}$ exceeds a certain threshold τ_{rel} we can say that a person cuts the LOS of the stream.

Since each stream is noisy by itself we can use the average of relative variance RV_{av} of different streams covering an area as a better metric for detection and compare this average to the threshold $\tau_{rel} \cdot RV_{av}$ for a certain area, covered by N streams is given by

$$RV_{av} = \frac{1}{N} \cdot \sum_{i=1}^N \frac{var_{oni}}{var_{offi}} \quad (4.6)$$

In fig 3.4 we can see the relative variance $\frac{Var_{oni}}{Var_{offi}}$ of six streams when the person moves in each of four zones. From the figure it is clear that setting the threshold value $\tau_{rel} = 1.98$ is reasonable to get a 100 % detection probability. Although decreasing the threshold may increase the detection probability at the same time it will increase the false alarm probability.

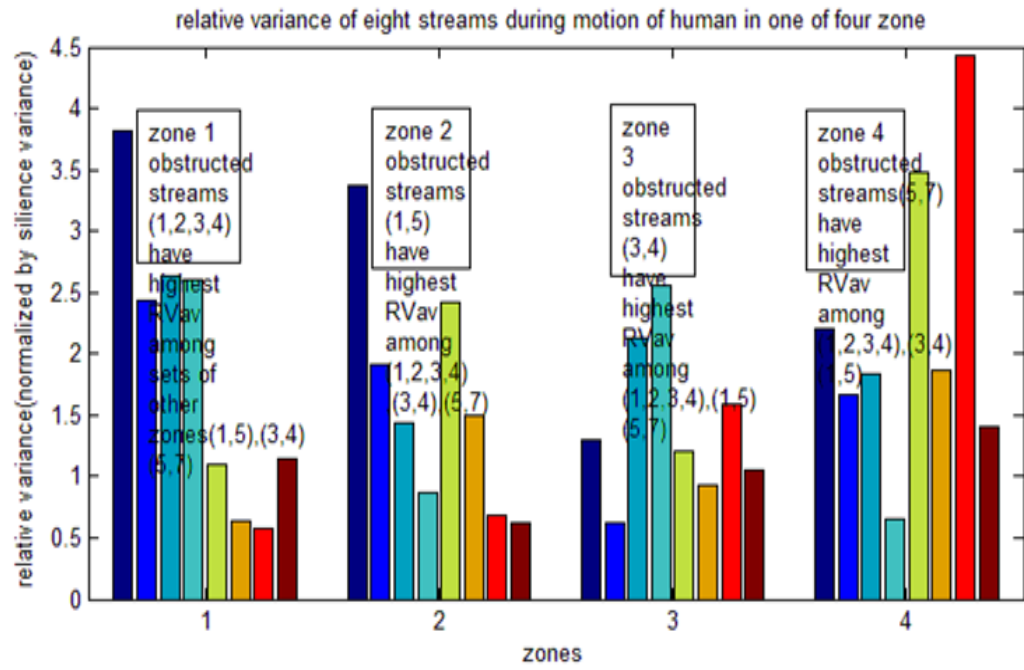
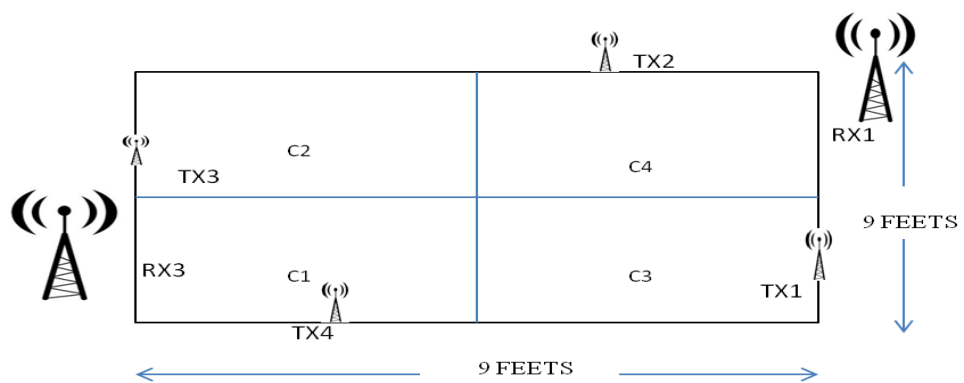


Figure 4.4: Relative variance $\frac{Var_{oni}}{Var_{offi}}$ of eight streams when person move in each of the four zones



System parameter

parameter	Default value	meaning
K	4	Number of cells
L	8	No of radio links
Ntrn	1000	No of training data per cell

Figure 4.5: system parameter

Chapter 5

performance evaluation

Average error : Average error distance is defined as the average distance between the center of the actual cell and the center of the estimated cell

Localization Accuracy : is defined as successful estimation rate

i.e

$$\sum_I^N \frac{I(Y_i = \hat{Y}_i)}{N} \quad (5.1)$$

The objective of a localization system is to maximize the likelihood of correctly estimating an subjects location and minimize the average distance between the estimated location and the actual location. In our system, we have proposed a four cell based localization and detection shown in table 4.1 and find a test successful if the estimated cell number matches the actual cell number.here we found that as average error is increasing from zero inch to 90 inch the localization error is increasing from 70 to 100 percent

AVERAGE ERROR	NO OF TEST COUNT	NO OF CORRECT DETECTION	NO OF FAULSE DETECTION	LOCALIZATION ACCURACY
OBJIS zero inch FROM CENTRE OF CELL	10	7	3	70%
OBJIS 54 inch FROM CENTRE OF CELL	12	10	2	83.3%
OBJIS 72 inch FROM CENTRE OF CELL	10	9	1	90%
OBJIS 90 inch FROM CENTRE OF CELL	5	5	0	100%

Table 5.1:

Chapter 6

Conclusion and future work

In this paper we introduce a DFP system based on the RSSI measurements was done to localize and track the intruder through the aggregated alerts received from the nodes of the network. Within this scope, implementation of an easily configurable, easy to use, real time intrusion detection and tracking system was planned. the aim was to examine the strengths of system while avoiding the weaknesses, to assure maximal performance for the developed system while considering the limited resources set by the sensor networking platforms

An important aspect of the work was validating interference produced by coexisting systems and identifying the sources of RSSI variability. To establish this, interference of WLAN was investigated and the influence to the WSNs performance was discussed. in order to maximize the performance of the developed system. The impact of transmission power, nodes distance, and the surrounding environment on RSSI variability were studied in order to determine a framework for the RSSI characteristics. The effect of a person to a nodes RSSI measurements was investigated and the results were used to develop an algorithm capable of detecting LoS crossings. The algorithms performance was validated and proved to correctly raise the alerts when LoS crossings occur. Also false alerts were detected but they were caused by the imperfect radiation pattern of the omnidirectional antenna and the reflections of radio signals from nearby obstacles.

The work we have done rise several interesting questions for future research. First we need to explore novel methodologies to locate multiple users. Secondly, we find that we can achieve better localization accuracy when some of the RF devices fail, which suggests the opportunities to develop algorithms to optimize deployment. Also, we need to explore new algorithm to achieve even better localization accuracy.

Bibliography

- [1] G. Kurillo, R. Vasudevan, E. Lobaton, and R. Bajcsy, A framework for collaborative real-time 3D teleimmersion in a geographically distributed environment, *IEEE International Symposium on Multimedia (ISM 2008)*, Berkeley, CA, December 15-17, 2008.
- [2] Yun-Suk Kang, Yo-Sung Ho, “Geometrical compensation for multi-view video in multiple camera array,” *ELMAR*, 2008. *50th International Symposium*, vol. 1, pp.83-86, 10-12 Sept. 2008.
- [3] H. Kim, I. Kitahara, R. Sakamoto, K. Kogure, “An Immersive Free-Viewpoint Video System Using Multiple Outer/Inner Cameras,” *Third International Symposium on 3D Data Processing, Visualization, and Transmission*, pp.782-789, 14-16 June 2006.
- [4] R. Vasudevan, G. Kurillo, E. Lobaton, T. Bernardin, O. Kreylos, R. Bajcsy, K. Nahrstedt, “High-Quality Visualization for Geographically Distributed 3-D Teleimmersive Applications,” *IEEE Transactions on Multimedia*, vol. 13, no. 3, pp.573-584, June 2011.
- [5] Bennett Wilburn, Neel Joshi, Vaibhav Vaish, Eino-Ville (Eddy) Talvala, Emilio Antunez, Adam Barth, Andrew Adams, Marc Levoy, Mark Horowitz, “High Performance Imaging Using Large Camera Arrays,” *Proc. SIGGRAPH*, 2005.
- [6] J. Canny, “A Computational Approach To Edge Detection,” *IEEE Trans. Pattern Analysis and Machine Intelligence*, 8(6):679–698, 1986.
- [7] Michael Elad, *Sparse and Redundant Representations. From Theory to Applications in Signal and Image Processing*, 1st Edition, Springer, 2010.
- [8] E. J. Candes, M. B. Wakin, “An Introduction To Compressive Sampling,” *IEEE Signal Processing Magazine* vol.25, no.2, pp.21-30, March 2008.
- [9] S. Mallat, *A Wavelet Tour of Signal Processing*, 3rd. Ed., Academic Press, 1998.